MINNESOTA TECHNICAL NOTE NO. 8

U.S. Department of Agriculture **Natural Resources Conservation Service**
St. Paul, MN **February 23, 2010**

DESIGN OF STREAM BARBS for LOW GRADIENT STREAMS

Introduction

Stream barbs are rock structures that extend into the stream to modify flow patterns and bed topography. They are very low structures that should be completely overtopped during channel-forming flow events (1.2 year to 1.5 year return period). Channel-forming flow or bankfull flow is defined as flow that transports the greatest amount of sediment over a long period of time and controls the channel geometry. Bankfull DOES NOT mean flow to the top of the channel bank.

Each stream channel and project site is unique. Geomorphic characteristics, such as meander pattern, width/depth ratio, radius of curvature, particle size distribution, channel gradient, and pool/riffle spacing, all impact the effectiveness of stream barbs. Onsite evaluation of the appropriateness and utility of stream barbs is necessary. They are most effective in streams with slopes less than three percent.

This technical note is intended for low gradient streams, often with channel slopes of 1% or less. The primary criterion is that the flow is subcritical. For streams with supercritical flow with a Froude number of 1.7 or larger, Technical Note 12 from Idaho (see reference list – "Design of Stream Barbs, 2001) should be used.

Stream barbs redirect stream flow with a very low weir and disrupt the velocity gradient in the near-bank region. The low weir section is pointed upstream and forces the water flowing over the weir into a hydraulic jump. Flowing water turns to an angle perpendicular to the downstream weir face causing the flow to be directed away from the streambank. The weir effect continues to influence the bottom currents even when the barb is submerged by flows greater than the channel-forming flow. The disruption of the velocity gradient reduces channel bed shear stress and interrupts sediment transport – this results in sediment deposition adjacent to the barb. The local flattening of water slope upstream of the barb causes an eddy and sediment deposition. The flow separation caused by the hydraulic jump and flow redirection downstream of the barb creates an eddy, which also promotes deposition.

Stream barbs are used for bank protection measures, to increase scour of point and lateral bars, to direct stream flow towards instream diversions, and to change bedload transport and deposition patterns. Other benefits of stream barbs include reducing the width to depth ratio of a stream channel and providing pool habitat for fish. Although rootwads can be added into barbs to increase the habitat value, they increase the risk of voids in the rock fill, poor foundation conditions, and increased uplift forces. If fish habitat is limited, consider creating habitat elements separate from the barbs if feasible.

Using stream barbs in conjunction with bioengineering methods is the most favorable combination. The barbs relieve direct streambank pressure from flow and vegetation provides for energy dissipation and sediment deposition. The vegetation is the long-term stabilizing factor.

Success Guidelines

The guidelines below determine whether a stream barb installation is considered successful.

1) Erosion of the bank appears halted where the barbs were installed – that is, vegetation is established in previously eroding areas.

2) The site has experienced at least one storm of the 5 to 10 year return period size, and the rock has not shifted out of place.

3) The rock has not shifted due to ice action.

4) Siltation is occurring at the toe of the slope that adds to the previously eroding bank.

Stream barbs are not universally applicable. The goal is to work with the stream, not against it.

Rock for Stream Barbs

Rock for barbs shall be durable and of suitable quality to assure permanence in the climate in which it is to be used. The rock shall be sound and dense, free from cracks, seams, and other defects that would tend to increase deterioration from weathering, freezing and thawing, or other natural causes. The rock fragments shall be angular to subrounded in shape. The least dimension of an individual rock fragment shall not be less than one-third the greatest dimension of the fragment. Rock will have a minimum specific gravity of 2.5.

Determine the D_{50} rock size for the bank full flow condition using a recognized riprap design method such as MN TR3. After determining the D_{50} size for stream bank protection, double the diameter to obtain the D_{50} for the stream barb. The D_{100} rock size (or largest rocks) for the barb shall be at least 3 times the calculated D_{50} size. The minimum rock size in the barb should not be less than the calculated riprap D_{50} size.   If the Isbash curve (EFH Chapter 16, page 16A-1) is used for determining the size of rock, multiply the resulting rock size by 3.0 to determine the D_{100} size for the rock. A D_{50} of 6 inches (calculated in TR3 for stream bank protection) has worked in low gradient streams in Minnesota when increased in size per the relationships below. Use of a MnDOT gradation for riprap improves availability of rock.

Once the riprap D_{50} is obtained, use the gradation below:

$D_{50\text{-barb}} = 2 \times D_{50\text{-riprap}}$

$D_{100\text{-barb - minimum}} = 3 \times D_{50\text{-riprap}}$

$D_{\text{minimum-barb}} \geq D_{50\text{-riprap}}$

Use the riprap gradation information from MNTR3 to convert the $D_{50\text{-barb}}$ size to an entire gradation. The table is given below.

Size of Stone	Percent of total weight smaller than the given size
1.5 to 2.0 x $D_{50\text{-barb}}$	100
1.3 to 1.8 x $D_{50\text{-barb}}$	85
1.0 to 1.5 x $D_{50\text{-barb}}$	50
0.3 to 0.5 x $D_{50\text{-barb}}$	15

Rock in the weir section of the barb should be well-graded in the D_{50} to D_{100} range. The largest rocks should be used in the exposed weir section of the barb. Rock sizing depends on the size of the stream, maximum depth of flow, entrenchment, and ice and debris loading, and the possibility of increased shear stress in a curve. Adjustments may be necessary for a given local area.

General Design Guidance

1. Location and number of barbs -- Stream barbs are typically placed along the outside of a bend or meander where the thalweg is near the streambank. In Minnesota's low gradient streams (frequently less than 1% bed slope), which may have minimal geomorphic features such as riffles and pools, no apparent thalweg may be observed.

The number of barbs required at any given site will be determined by the (1) barb spacing, (2) the length of the eroding meander bend, (3) channel geometry, and (4) average width of the stream. The erosion will primarily be on the outside of the curve, but this will swing between the left and right banks depending on the number of meanders in a stream.

The furthest upstream barb should be located just upstream of the area that is first impacted by flood flow erosion. Some stabilization effect may occur upstream of the first barb, perhaps 25 to 50'. Often barbs do not need to extend to the downstream extent of the eroding bank, as upstream barbs will modify the angle and distribution of velocity, stopping the erosion. In general, in a stream with moderately regular meander patterns, barbs should not be placed downstream of the ¾ turn length (see Figure 1).

A sediment bar may form downstream of the downstream-most barb. This may be an indication that too many barbs have been installed or they are too close together and too much energy is removed from the flow. The transport competence is reduced and the sediment accumulates.

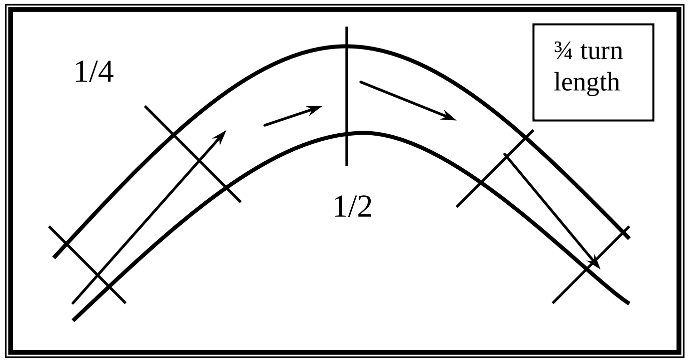


Figure 1. Do not place barbs downstream of the ¾ turn point.

2. Height – The height of the stream barb is generally determined by the elevation of channel-forming flow discharge (approximately a 1.2 to 1.5 year return period event). For ungaged streams, channel forming discharge can be determined using field indicators such as bed features and the presence or absence of vegetation. The channel-forming or "bankfull" elevation is not necessarily the top of the bank; in fact, it's often lower than that. The height of the barb is measured from the stream bed to the top of the barb but this dimension is rarely used since the top of the barb slopes into the water and the channel bottom is rarely uniformly flat.

The structure is intended to function as a weir and is therefore nearly flat along its length (slope should not exceed 10H:1V) but MUST always have a downward slope away from the stream bank. A slope of 20:1 has been satisfactory in Minnesota. Slopes between 10:1 and 30:1 are expected to give satisfactory results. Barbs constructed with flat weir sections may lose a few rocks from the center of the barb resulting in a negative slope and essentially force water closer to the bank. In flatter gradient streams, the bed is too variable to measure the height of the barb from the bed. At the streambank end, place the barb below the channel-forming discharge elevation (CFDE) by 30 to 50% of the average depth of the cross-section (D_{avg}) at channel forming discharge.

The relative height between successive barbs is important. The difference in height between barbs should approximate the energy grade line of the stream regardless of local variations in bed topography. In Minnesota, this difference can be small. See the example problem.

To reduce scour depths, decrease the barb height. Higher barbs, up to the channel forming flow elevation, cause greater flow convergence, and thus greater scour depths.

3. Spacing – Proper spacing of barbs is necessary to prevent the stream flow from cutting between two barbs and eroding the bank. A vector analysis (plotting the proposed barbs with vectors projecting at right angles to the downstream side of the barb) can give some indication of flow lines and flow interception by subsequent barbs. Given that the flow will leave the barb in a direction perpendicular to the downstream weir face, the subsequent barb should be placed so that the flow nearest the bank will be captured in the center portion of the next downstream barb before the stream flow intersects the bank. Typically, barbs influence flow patterns for a distance downstream of 4 to 7 times the barb's length, although much local variation has been seen.

Barbs may be spaced closer together in the sharpest part of the curve to turn the flow adequately. An additional barb may be needed at the downstream end, but this may not be apparent until the installation is in progress and flow patterns observed. The designer may wish to have a plan in mind for delivery of additional rock if another downstream barb is deemed wise on construction day and have concurrence with regulatory permits obtained.

4. Angle – The structure should project upstream such that the flow is directed away from the streambank. A vector analysis can be used to estimate the angle required to turn the flow. See Figure 2. The angle between the barb and the tangent to the upstream bank will typically range from 50 to 80 degrees. Alignment should be based on the flow off the barb, assuming the flow perpendicular to the centerline of the barb. Note that this is quite different from high gradient streams where the angle may be 20 to 45 degrees from the tangent to the bank. The low velocities in northwestern Minnesota streams require only a small modification to the cross-stream vector. If the angle were sharper, the flow is turned almost directly into the opposite bank, and the currents moving downstream are not sufficient to alter the vector.

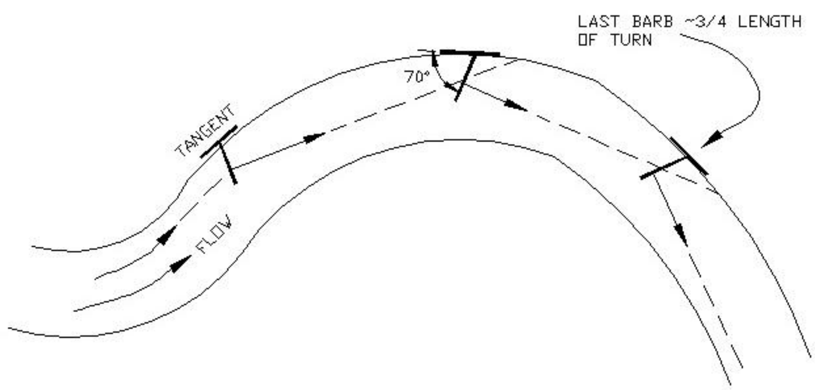


Fig. 2. Vector analysis for barb location

5. Length and Width – For most barbs, the effective length should be 10 to 35% of the channel-forming flow width (W). If a near-bank thalweg exists, the barb should cross it. Length and spacing are closely related.

The top width of a barb generally ranges from one to three times the D_{100} of the rock, or at least 3 feet. The top width may need to be increased to a total of 10-15 feet to accommodate construction equipment. Avoid barbs that have a section that is one rock in width, as ice may cause movement of the rock and a lone stone is more vulnerable than a cluster. Wider structures will result in a more uniform, stronger hydraulic jump. Wider structures should be used if a deep scour hole downstream of the barb is expected.

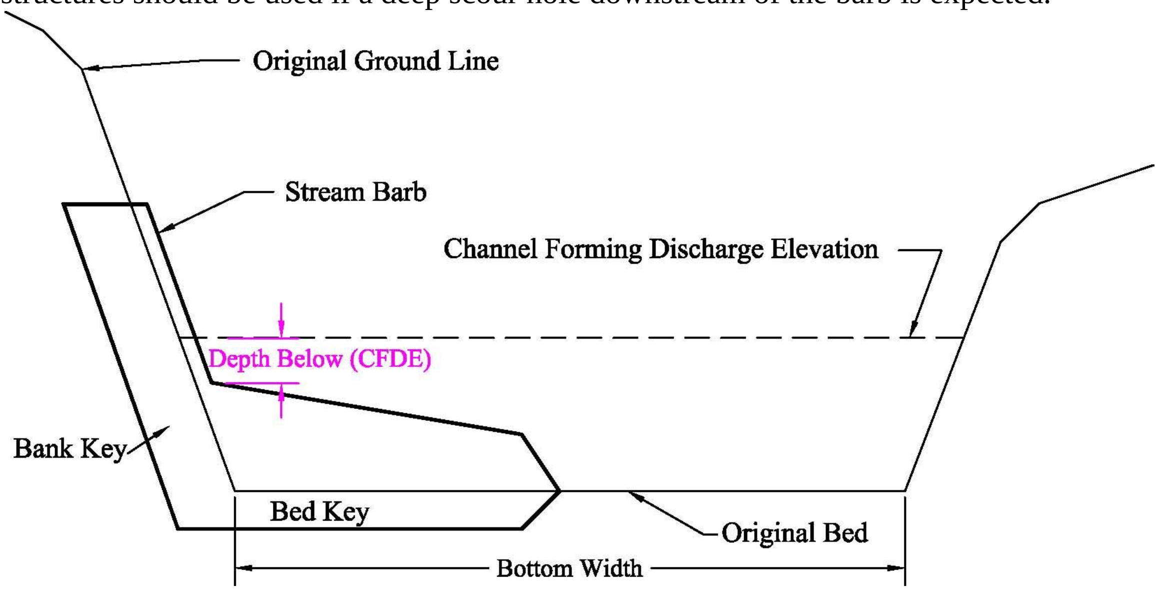


Figure 3. Parameters for barb placement and sizing

6. Height and Length of Bank Key – The barb section on the bank slope should conform to the slope of the bank. The weir elevation at the stream bank should be below the channel-forming discharge elevation (CFDE) (1.2 to 1.5 year return period). The top of the key must be high enough to prevent water from flowing around and eroding behind the structure for the design event. Banks that are frequently overtopped will require a more extensive key that extends further back into the bank. Bank materials will also need to be considered when designing the dimensions of the key.

The purpose of the bank key is to protect the structure from flanking due to erosion in the near bank region. Key the barb into the bank a minimum distance of 8 feet or 4 x D_{100}, whichever is greater. The width of the key trench shall be at least equal to the D_{100} rock size. Refer to Minnesota Standard 580 for streambank and lakeshore protection to determine the frequency event for which the barb must protect.

Some publications have a diagram of the barb from the plan view that shows that the key is at a different angle to the flow than the barb itself. When construction is underway, it has been easier for the contractor to place the key at the same angle as the barb itself, allowing the equipment to move out onto the barb to lay the stream end of the barb.

A non-woven geotextile should be installed under the barb on the bank cut only. The barbs are installed deep enough and wide enough so that energy has been dissipated that would otherwise remove bed sediment, eliminating the need for geotextile in the stream bed which is difficult to install.

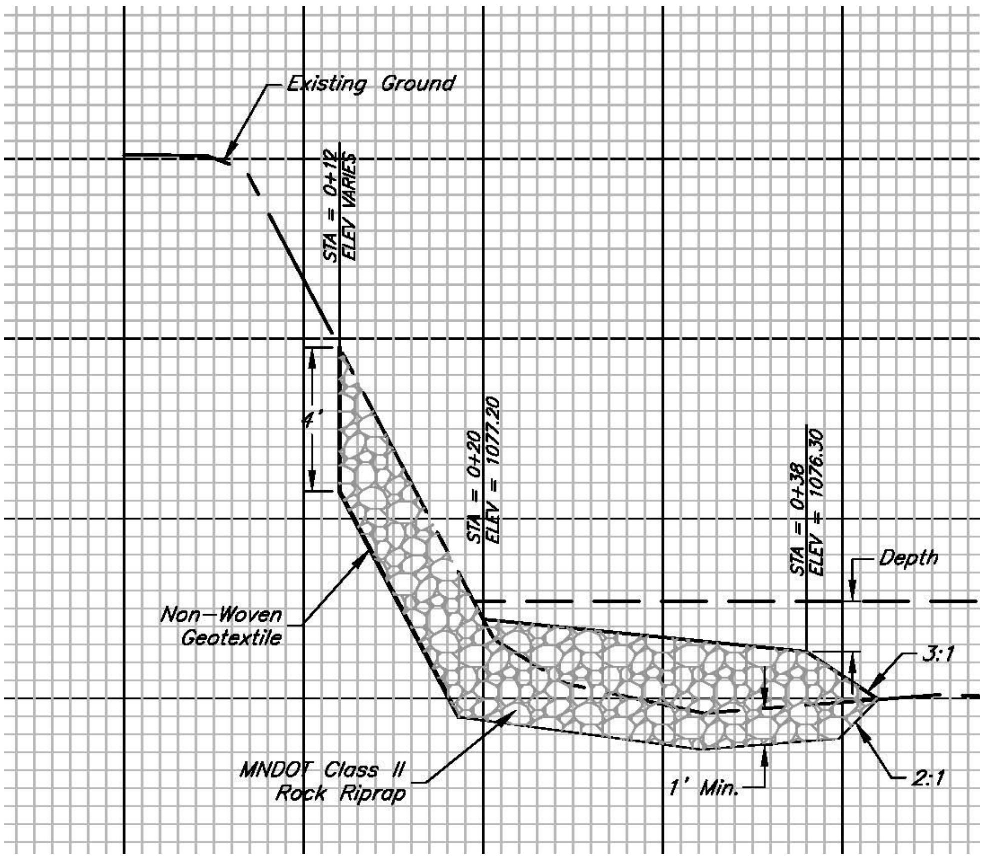


Figure 4. Example of keying barb into bank from a specific project; note that the dimensions and rock riprap gradation may vary

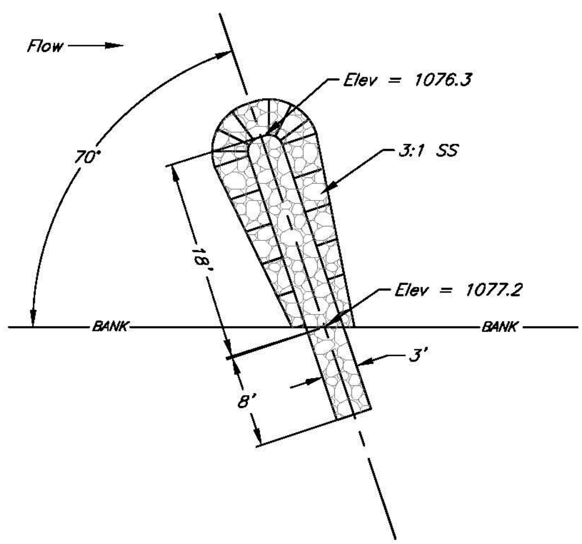


Figure 5. Sample plan view of barb with key into bank; dimensions and angles will vary based on actual site design.

7. Depth of the Bed Key – The bed key depth should be determined by calculating expected scour depth around the tip of the structure. Minnesota streams with velocities less than 3 feet per second at the channel forming discharge have little scour and need a limited bed key. These sites typically have a Froude number less than 1.0 which indicates subcritical flow. Satisfactory results have been obtained assuming the bed scour will be no more than 12 inches, and placing the rock key into the stream bed about one foot. The barb causes a pool to be formed at its tip. See Figure 7.

8. Hydraulics – The amount of flow forced over the barb can be approximated by the amount of channel area the barb crosses:

$Qb = Ab/At(Qt)$ where,
Qb is the portion of the channel forming flow over the barb in cfs
Ab is the channel area the barb impacts
At is the total channel forming flow area
Qt is the total channel forming flow in cfs

In order for the barb to have an impact on the stream, the Ab/At should be greater than 0.1.

$$Ab/At \geq 0.10$$

Ab is the area of flow for water passing over the barb, sq. ft.
At is the total channel forming flow area at the CFDE as if the barb weren't there, sq. ft.

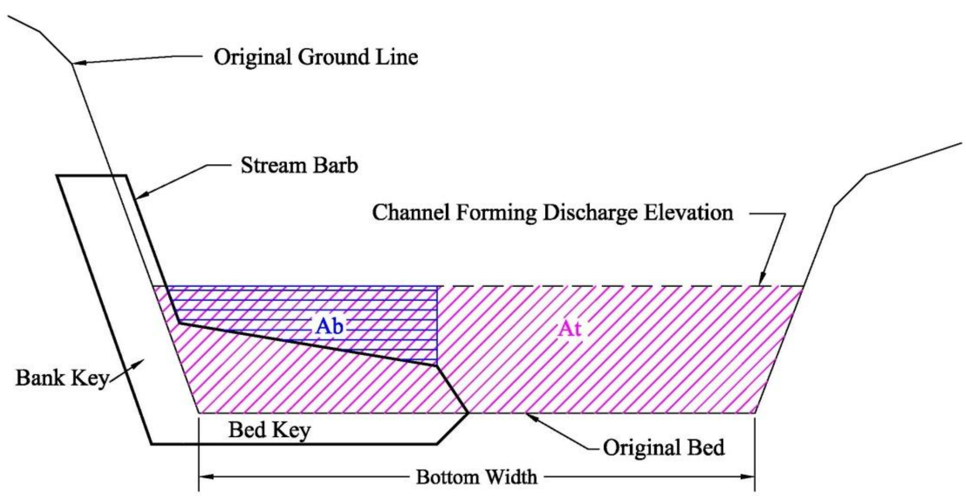


Figure 6. Relationship between At and Ab for calculating barb hydraulics; not to scale

Secondly, the height of flow over the barb should be checked with a weir formula. The height of flow over the barb added to the height of the barb should not be more than 120% of the average depth of channel forming flow or excessive backwater effects will be created.

$H_f = (Q_b/C/L)^{2/3}$ where,

H_f = height of flow over the barb, feet

Q_b = flow over the barb in cfs

C = broad crested weir coefficient, generally about 2.8

L = total length of the barb, feet

Thirdly, low gradient streams tend to have subcritical flow and thus Froude numbers less than 1.0.

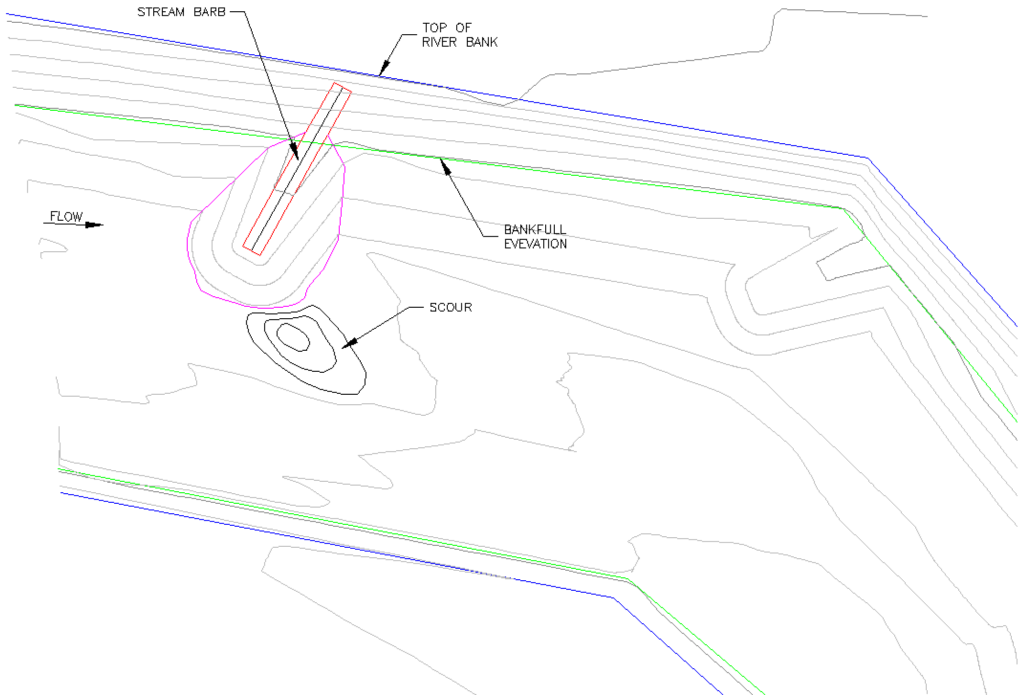


Figure 7. Scour observed on barb site in Todd County, Minnesota, 2006.

9. Construction – Stream barbs should be constructed when the flow is at or below bankfull conditions to minimize in-stream disturbances. Short barbs can be constructed from the bank while long barbs may require the use of the barb surface as a platform during construction. The barb width can be reduced as the equipment works back from the tip of the barb towards the bank. The rock should never be end dumped. Construction should always start at the upstream end of the project site. Alterations to the design during construction often occur. The designer should be on-site to authorize changes and oversee installation. Barb spacing may need to be adjusted by observing the flow pattern in the river after each barb is installed, with consideration to flow patterns at bankfull depth.

10. Vegetative Measures – Barbs are often used in combination with vegetative measures. If the bank slope is at its natural angle of repose, natural regeneration may result in a good vegetative stand within 1 to 2 years of installation. If the bank is vertical or nearly so, it may be wise to pull the slope bank – even to 1:1 – to allow vegetation to start establishing itself. The banks may be seeded and mulched if reason exists for needing rapid vegetative establishment. Mowing is not recommended for the vegetated areas between barbs.

The existence of riparian buffers along streams is very important to the success of stream stabilization projects. Where trees have been cleared and row crops planted to the edge of the stream, the bank stability is often threatened. A grass buffer is helpful; a buffer that is a mixture of grasses and trees solidifies the root mass to resist erosion.

An island may lie in the stream. If it appears to have been in place for quite some time (i.e., has mature trees on it), the barbs are best designed using the channel width only between the island and the bank for determining barb length. If tree clumps exist on the bank, they may be key for erosion control. Make every attempt to install the barbs in harmony with the existing tree roots.

<u>11. Example </u>– Stream barb design

A site is located in Todd County, Minnesota on the Long Prairie River. A gaging station on the Long Prairie River was identified for estimating the parameters to go into the USGS regional equations as described in USGS publication 97-4249, "Techniques of Estimating the Magnitude and Frequency of Floods in Minnesota". Using the ROI Proximity method, the discharges for the Q_2, Q_5, Q_{10}, Q_{25}, Q_{50} and Q_{100} events were calculated. These were plotted on log normal paper and extrapolated to learn that the $Q_{1.5}$ is 401 cfs and the $Q_{1.2}$ is 293 cfs. The drainage area was estimated at 145 square miles using USGS's Interactive Minor Watershed web site. The Q_{10} discharge was calculated by USGS at 1350 cfs.

In the field, the channel forming discharge elevation was estimated at assumed elevation 1077.70 by observing indicators of exposed roots and low terraces. The survey cross-section was placed in the AreaVol program and the cross-sectional area, A, was calculated to be 140.2 sq. ft. at this elevation. The wetted perimeter, P, was 58.2' so hydraulic radius $R = A/P = 2.4$ ft. The slope was used from the USGS publication as 0.0009 ft/ft. Using Manning's equation with an n value of 0.035, the velocity was calculated at 2.35 ft/sec. $Q = VA = 2.35$ ft/sec x 140.2 ft^2 = 330 cfs, which is approximately the $Q_{1.3}$ discharge.

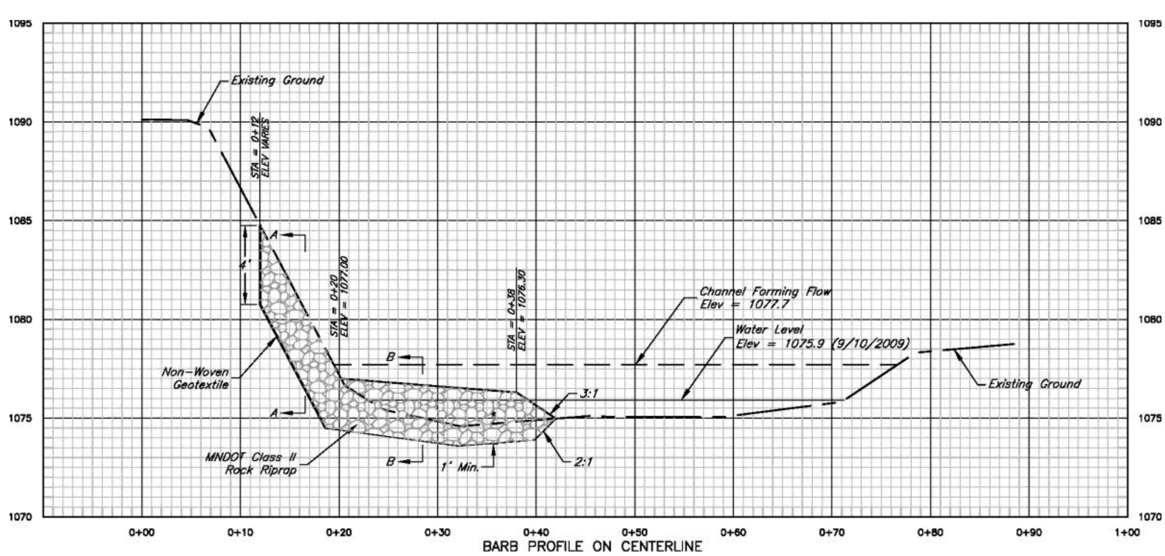
MN TR3 was used to calculate the rock size needed for stream bank protection. The d50 was 3 inches. This was doubled for use in the barbs to 6 inches.

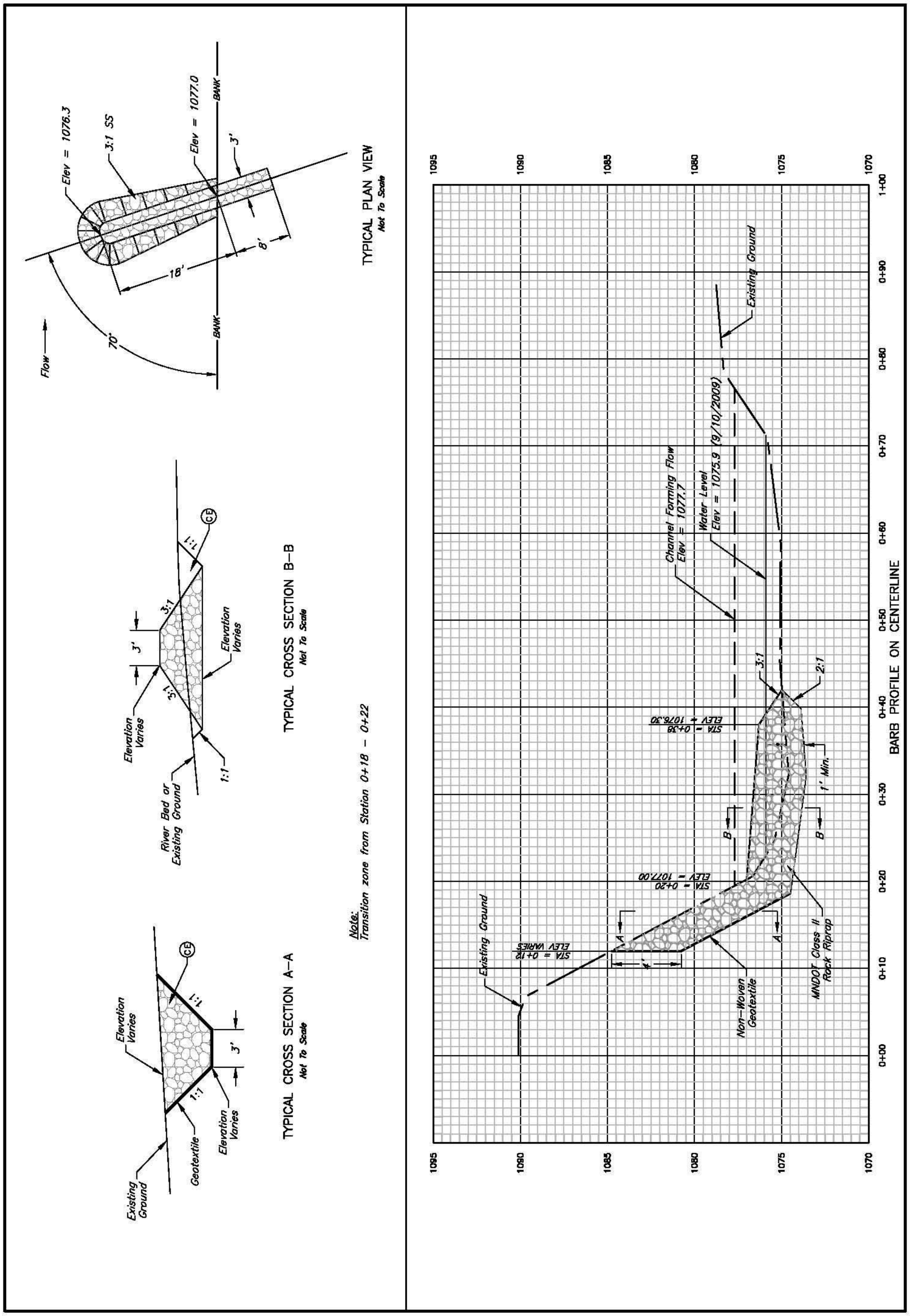
The survey was plotted and the first barb drawn entering the curve where the erosion begins. The channel width is 57.6 feet at the channel forming discharge elevation of 1077.7. A barb length of 18 feet was chosen by drawing the barb onto the survey and noting where the flow lines would go when they are turned 90 degrees to the centerline of the barb. 18 feet is 31% of the 58 foot width so this meets the criteria in part 5 of this technical note. The top of barb will have 25:1 slope. After noting where the flow lines would again impact the bank, the location of the second barb was selected to be about 90 feet downstream of the first barb. Again, a barb length of about 18 feet was chosen. A third barb was located using the flow arrows coming from the second barb. This was about 90 feet downstream of the second barb and a length of 18 feet was again used. Only 3 barbs were designed for this site because any further barbs would have been placed on land owned by others from whom permission had not been sought. If land ownership had not changed, the barbs would have continued until the last barb was at or very near to the ¾ point through the length of the curve (see Figure 1).

The average depth in the cross-section at the channel forming discharge was 2.4 feet. This can be most accurately calculated by taking the cross-sectional area, A, (here 140.2 sq. ft.) and dividing it by the top width of 57.6 feet. The barb should be placed 30-50% of this depth below the channel forming discharge elevation or 0.7 ft to 1.2 ft. below elevation 1077.7. The barb top should be between elevation 1076.5 and 1077.0. Because of the extremely flat bed slope in this reach, the height difference noted by elevation of the barb tops in 90 foot spacing is negligible. The bed slope of 0.0009 ft/ft x 90 feet of distance change is 0.08 ft. which would be hard to achieve with large rock. However, if the project involves many barbs, the designer should consider the overall elevation change that may be needed between the first and last barbs.

The barb top was chosen initially to be at elevation 1076.3 (end), 1077.0 (bank) [25:1 barb slope]. With a spacing of 90 feet, and a barb length of 18', this ratio is 5.0, which falls in the range given in part 3 (Spacing) for the barb's typical influence compared to the length of the barb. An angle of about 70 degrees from the tangent of the bank was selected during the analysis of the flow on the plan view drawing. This is consistent with part 4 (Angle).

The width of the barb at its most waterward point was designed to be at least 2.25 feet or 3 times the minimum D_{100} of 9 inches. The key was selected to be placed at least 8 feet into the bank. Four times D_{100} was 3 feet, so 8' was longer and used for the design, per part 6 (Height and Length of Bank Key).





Sample plan sheet for example given.

According to MN standard 580, the protection only had to extend to the Q_5 elevation, but Q_{10} was used to build in an additional factor of safety. The Q_{10} elevation was estimated to be elevation 1081.5 based on calculations using Manning's equation. The depth of the bed key was used at 12" or 1 foot due to the low gradient stream and expectations of limited scour potential, per part 7 (Depth of the Bed Key). This has proved adequate so far in the 9 years the barb has been in place.

Area of flow over barb (Ab) = 19.07 sq ft. Area total (At) = 140.2 sq. ft. Ab/At = 0.136
0.136 $\geq$ 0.10 This meets the criteria in part 8 (Hydraulics).

Davg = 2.5 ft. 120% of Davg = 3.0 feet. Height of flow over barb = 0.9 (average) feet; height of barb above stream bed = 1.7 (average) feet. Add 1.7 to 0.9 = 2.6 feet. This is under the criteria in part 8 so acceptable. The maximum depth in a cross-section may not meet this criterion but the average depth should.

12. Acknowledgements

This technical note was prepared by Sonia Maassel Jacobsen, PE and Scott A. Smith, PE. Review and insights were provided by Rob Sampson, PE, Idaho NRCS, and John C. Brach, PE, Minnesota NRCS.

13. References

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Fig. 8. Swan Lake Township barbs

Fig. 9. Sediment bar forming downstream of downstream-most barb

Fig. 10. West central Minnesota site – flow being turned – post project installation

Figure 11. West central Minnesota site before stream barb installation (taken from opposite direction compared to Figure 10 photo, 2006)